E-137

ARR Feb. 1943

# NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

# WARTIME REPORT

ORIGINALLY ISSUED

February 1943 as
Advance Restricted Report

## SMALL-ORIFICE TUBES FOR MINIMIZING DILUTION

## IN EXHAUST-GAS SAMPLES

By Harvey A. Cook and Walter T. Olson

Aircraft Engine Research Laboratory
Cleveland, Ohio



NACA

WASHINGTON

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

ADVANCE RESTRICTED REPORT

# SMALL-ORIFICE TUBES FOR MINIMIZING DILUTION IN EXHAUST-GAS SAMPLES

By Harvey A. Cook and Walter T. Olson

## SUMMARY

An investigation was undertaken to find a means of obtaining undiluted exhaust-gas samples from a Wright R-2600-B aircraft engine equipped with short individual stacks (approximately 10 in. long). Preliminary tests to aid in determining the best design, location, and orientation of orifices ranging from a 0.002-inch slot to an 0.1875-inch-diameter circular opening at the entrance to an exhaust sampling tube were made with a small Briggs & Stratton engine. Sampling tubes 1/4 inch in diameter and with a 0.010-inch-slot orifice were installed in all 14 cylinders of the Wright engine after the correct location and orientation for the sampling tubes had been determined in tests on a single cylinder of this engine. Samples were analyzed by an Orsat portable apparatus and by an NACA mixture indicator.

The results indicated that (1) small round or slot-type orifices at the entrance to the sampling tube when located and oriented to receive directly the impact pressure of the exhaust gases minimize dilution in the exhaust-gas samples; (2) dilution, if present at the point of sampling in the exhaust stack, can be detected by successively operating the sampling tube at different pressures; (3) samples taken from the Wright engine with the sampling orifice not receiving the full exhaust impact pressure were diluted approximately 50 percent with air; whereas, in samples taken with the sampling orifice correctly oriented, dilution was negligible or nonexistent.

## INTRODUCTION

Obtaining exhaust samples from an aircraft engine presents some difficulties. When the sampling tube is placed in the exhaust stack with the end of the tube as close as practicable to the valve, undiluted gas samples have been obtained from

exhaust stacks of sufficient length to have prevented the air at the open end of the stack from mixing with the residual gases in the stack between exhaust events for that cylinder. Dilution by air in short individual stacks and dilution by gases from adjacent cylinders if a collector ring is used spoil the samples and introduce errors in the study of individual cylinder performance by exhaust-gas analysis. The present investigation was undertaken to find a means of obtaining undiluted samples from a Wright R-2600-B aircraft engine equipped with very short individual stacks (approximately 10 in. long).

An undiluted sample could be obtained from a device that would permit sampling flow from the exhaust stack during only the exhaust event when the gas flow was well established in the stack. It was thought that a sampling tube with a small orifice at the entrance would operate to eliminate dilution of exhaust samples because of the cycle of pressure changes that occur in the exhaust stack. The high-pressure period in the cycle with a high impact pressure acting on the small orifice would fill the sampling tube and would build up a pressure in it. This pressure would remain above the pressure in the stack throughout the rest of the cycle if the rate of sampling were properly adjusted. It was believed that this retention of a positive pressure in the sampling tube would prevent the entrance of any gases during the low-pressure period in the cycle, because gas trapped in the sampling tube would slowly flow into the stack during this period.

Preliminary tests of the use of a small orifice in a sampling tube were conducted with a single-cylinder Briggs & Stratton engine. Data were collected that related the flow pattern in the exhaust stack, the pressure and rate of sampling, and the shape, size, and location of the orifice, with the composition of the sample. Tests were then made with the orifice of the best size and shape, first on one cylinder and then on all cylinders of the Wright R-2600-B aircraft engine, to determine the efficacy of this method of sampling.

The tests were conducted at the National Advisory Committee for Aeronautics, Aircraft Engine Research Laboratory, Cleveland, Ohio, during June 1942.

## APPARATUS AND METHODS

The use of small orifices to minimize dilution was first tested on the Briggs & Stratton engine shown in figure 1. A straight exhaust stack coming directly from the valve port provided a cyclically varying pressure that was applied to various orifices in sampling tubes. The sampling tubes were used at different positions in and out of the stack to test the effect of location of the orifices on dilution of the samples. Figure 1 shows a sampling-tube orifice located in the center of the open end of the exhaust stack. Sampling pressure was regulated either by controlling the rate of sampling or by dividing the flow of gas entering the sampling tube into two branches. In the method of dividing the gas flow, the sample for analysis was collected from one branch while gas continuously escaped to the atmosphere against an adjustable head of water in the other branch.

Figure 2 shows a number of the small orifices tested. Orifice dimensions ranged from a 0.002-inch slot to a 0.1875-inch-diameter circular opening. The slot-form sampling-tube orifice was adopted to facilitate the making of openings down to 0.002-inch wide in any kind of metal tubing without encountering the difficulty of drilling very small holes.

Tests were then performed on one exhaust stack of a Wright R-2600-B aircraft engine to determine the proper location and orientation of the orifice. The slot orifice used was initially directed along a line parallel to the axis of the stack and at the flange, as shown in the left-hand position of figure 3. When this direction of orifice was found unsuitable, an adjustable tube was installed for testing (fig. 4). The position of the sampling tube that permitted the slot orifice to be directly subjected to the impact pressure of the exhaust gases was found to be the position illustrated by the right-hand portion of figure 3.

Finally, sampling tubes were welded into the other 13 exhaust stacks of the Wright engine. The sampling tubes were 1/4-inch stainless-steel tubing with a 0.010-inch slot orifice and were 6 inches long (fig. 5). A 1/4-inch copper sampling tube was attached to the stainless-steel tubing by standard fittings. The sampling tubes were extended to a convenient point outside the test cell and were 30 to 35 feet long. Figure 6 shows how sampling tubes were mounted in exhaust stacks from a front cylinder and from a rear cylinder. The difference in position of

the sampling tube for front and rear cylinders was due to the valve arrangement on the engine. In both cases the orifice was faced toward the exhaust-valve guide.

Samples for chemical analysis were simultaneously withdrawn from all 14 sampling tubes. Alternately, any one of the 14 sampling tubes was connected to an NACA mixture indicator in the test-cell control room.

Occasional carburetor adjustments were made during the course of this investigation, but all data used in comparisons were obtained with a fixed carburetor setting.

The comparison of the action of the small orifices to determine the best size and type of construction was based on chemical analyses of exhaust samples, as was also the final testing of the orifices in the exhaust stack of the aircraft engine. All analyses were performed with a portable Orsat apparatus.

In order to aid in obtaining undiluted samples for reference analyses, a 3-foot exhaust stack was temporarily substituted for the short stack. This technique was employed for both engines.

## RESULTS AND DISCUSSION

### Briggs & Stratton Engine Tests

Gas flow in exhaust stack. - In the use of any sampling tube for exhaust-gas study, the location of the tube in the exhaust stack is the first point to be considered. The tube should be so located in the stack that the gas sample can be removed under its own pressure as well as with the least possibility of dilution. A study of the impact pressure of the exhaust gases showed the approximate flow pattern of the exhaust gases. In the short straight stack, a very uneven distribution of pressure near the valve showed that the gases starting through the stack were sweeping across the valve port and flowing mostly along the side of the exhaust stack opposite the valve opening. (See fig. 7.) When the orifices were located on the side of the stack opposite the valve head and close to the valve, the higher pressure there permitted sampling over a greater range of pressure and with a larger flow of gas.

Effect of round orifices. - The result of testing a series of round orifices to determine the effect of orifice size on sample composition was that small orifices were shown to minimize dilution better than large orifices. Figure 8 shows that twenty 0.0135-inch orifices substituted for a single orifice of equivalent area were more effective in minimizing dilution in the sampling tube than was the single large orifice, even though sampling pressures were not carefully controlled. For example, when the two sampling tubes were operated in turn at the open end of the stack, the analysis of the sample obtained through the 20 small orifices was 10.0 percent $CO_2$, 6.0 percent $O_2$; the analysis of the sample obtained through the single orifice was 9.0 percent $CO_2$, 6.8 percent $O_2$. This evidence is indicative of the validity of the introductory hypothesis.

Effect of sampling rates. - During the comparison of small and large sampling-tube orifices, large variations in analysis were evident when the sample was withdrawn at different rates. This phenomenon was investigated and the results are indicated in figure 9. At the open end of the exhaust stack an analysis of 3.5 percent $CO_2$, 14.9 percent $O_2$ was obtained with a 0.002-inch-slot sampling tube under conditions of rapid sampling, 10 milliliters per second. With the same tube at the same location, sampling done slowly enough to maintain a sampling pressure greater than atmospheric pressure (1 ml per sec) yielded a sample of 11.0 percent $CO_2$, 3.2 percent $O_2$. The actual undiluted exhaust-gas analysis under the prevailing conditions showed 12.8 percent $CO_2$, 1.2 percent $O_2$.

Effect of sampling pressure. - It is apparent from a consideration of the effect of rate of sampling on sample composition that sampling pressure is an important factor, because the sampling pressure and the rate of sampling bear an inverse relation to each other. When the sample was slowly withdrawn, the pressure in the line was high; when the sample was rapidly collected, the sampling pressure was low. Figure 10 shows that, at a point where dilution was a minimum and pressure in the exhaust stack was high, no variation of analysis could be obtained by varying sampling-tube pressure. Where dilution was severe, however, gas analysis was definitely dependent on the pressure used for sampling (fig. 11).

A method of detecting dilution and estimating its amount is to compare analyses obtained under different sampling pressures. This method would prove useful in determining the best location of a sampling tube in exhaust stacks of various shapes and sizes.

Effect of slot orifices. - The results of a study of the size of slot orifice at the entrance to the sampling line and the effect of pressure on its operation are shown in figure 12. For each slot-orifice size a definite sampling-tube pressure afforded the best elimination of sample dilution when dilution existed at the point of sampling. The sampling tubes were placed at the open end of the stack where dilution was very great. A severe test of their operation resulted. The need for using the correct pressure was clearly shown by the wide variation of gas-sample composition obtained by varying the sampling pressure.

The analysis indicating least dilution for each size orifice is plotted in figure 13 to provide a comparison of the relative values of the slot-orifice size. The data show that, for slot-type orifices, the sizes giving the least dilution were 0.008 to 0.012 inch wide and were operated with best results at 70 to 80 percent (fig. 12) of the maximum pressure obtainable in the closed sampling tube.

The graphs of figure 14 indicate that the 0.010-inch slot gives less dilution than the 0.008-inch slot. Both of these tubes permitted large gas-sample flow. Figure 15 shows the effect of sampling pressure on the composition of the sample for two different slot orifices. The 0.010-inch-slot orifice not only more successfully reduced dilution to negligible quantities but also permitted the larger flow of sample. Samples were easily obtained in 30 seconds.

## Wright Aircraft Engine Tests

Single-stack tests. - When a sampling tube with a 0.010-inch-slot orifice was first installed in one stack of the Wright engine (fig. 3, left-hand position), a pressure of only 0.3 inch of water existed in the sampling tube. Samples taken with the tube in this position were found to be approximately 50 percent air and 50 percent exhaust gas. The corrected position shown in figure 3 (right-hand position) as determined with the adjustable

testing tube changed the sampling pressure to 10 to 15 inches of water at engine speeds from 2000 to 2400 rpm. Samples obtained from this position of the sampling tube, when analyzed, showed dilution to be negligible or nonexistent. The composition of the undiluted exhaust gases was determined by analyzing a sample obtained from an exhaust stack with a 3-foot extension temporarily welded on. The slight change in direction of the orifice illustrated in figure 3 indicated not only that the orifice operated to eliminate serious dilution but also that dilution was present to a marked extent throughout the short stack.

Multistack tests. - When sampling tubes were installed in all 14 cylinders, similar sampling pressures were obtained from the tubes on all front and rear cylinders. This fact indicated that the installations were satisfactory.

A set of analyses of exhaust-gas samples obtained from the sampling tubes in the individual stacks of the Wright engine is given in table I. Values of fuel-air ratio were obtained from the NACA mixture indicator during the same run. With the mixture indicator located about 35 feet from the engine, the instrument was sensitive to changes in mixture ratio in about 1 minute. For comparison, fuel-air ratios were computed stoichiometrically from the $CO_2$ and $O_2$ analyses (reference 1). The fuel-air ratio varied little from cylinder to cylinder. The average of the fuel-air ratios recorded on the NACA mixture indicator and the average of the fuel-air ratios calculated from gas analyses was in good agreement, the difference being only 1.0 percent.

## CONCLUSIONS

From the investigation of sampling tubes with orifices ranging from a 0.002-inch slot to a 0.1875-inch-diameter circular opening, variously located and oriented in the exhaust stacks of a single-cylinder Briggs & Stratton engine and a Wright R-2600-B engine, it is concluded that:

1. Small round or slot-type orifices on the sampling tube are useful in minimizing dilution in the exhaust-gas samples.

2. The location and orientation of the orifice in the exhaust stack should be such that the impact pressure of the exhaust gases is directly applied to the orifice.

3. The pressure in the sampling tube should be maintained greater than atmospheric pressure and at a value that must be experimentally determined for each installation.

4. Dilution, if present at the point of sampling in the exhaust stack, can be detected by successively operating the sampling tube at different pressures. Low pressures give samples with the greatest amount of dilution.

5. The flow of sample obtained at the correct sampling pressure was ample to operate an NACA mixture indicator placed about 35 feet from the engine.

6. Samples taken from the Wright engine with the sampling orifice not receiving the full exhaust impact pressure were diluted approximately 50 percent with air; whereas, in samples taken with the sampling orifice correctly oriented, dilution was negligible or nonexistent.

Aircraft Engine Research Laboratory,
National Advisory Committee for Aeronautics,
Cleveland, Ohio.

## REFERENCE

1. Gerrish, Harold C., and Voss, Fred: Interrelation of Exhaust-Gas Constituents. NACA Rep. No. 616, 1937.

TABLE I

ANALYSIS OF EXHAUST-GAS SAMPLES FROM WRIGHT ENGINE

| Cylinder | Gases (percent) | | | Fuel-air ratio | |
|---|---|---|---|---|---|
| | $CO_2$ | $O_2$ | CO | NACA meter | Calculated |
| 1 | 4.7 | 0.7 | 14.3 | 0.109 | 0.106 |
| 2 | 4.6 | .6 | 13.8 | .107 | .107 |
| 3 | 4.7 | .6 | 13.8 | .105 | .106 |
| 4 | Sampling tube damaged | | | No sample obtained | |
| 5 | 4.5 | 0.3 | 14.8 | 0.107 | 0.109 |
| 6 | 4.9 | .2 | 14.8 | .105 | .108 |
| 7 | 4.5 | .6 | 14.0 | .108 | .107 |
| 8 | Sampling tube damaged | | | No sample obtained | |
| 9 | 4.5 | 0.3 | 15.3 | 0.109 | 0.109 |
| 10 | 4.2 | .5 | 15.2 | .113 | .109 |
| 11 | 4.7 | .5 | 14.0 | .111 | .107 |
| 12 | 4.7 | .6 | 14.4 | .108 | .106 |
| 13 | Sampling tube damaged | | | No sample obtained | |
| 14 | 4.7 | 0.6 | 14.5 | 0.104 | 0.106 |
| Average | 4.61 | .50 | 14.45 | .108 | .107 |

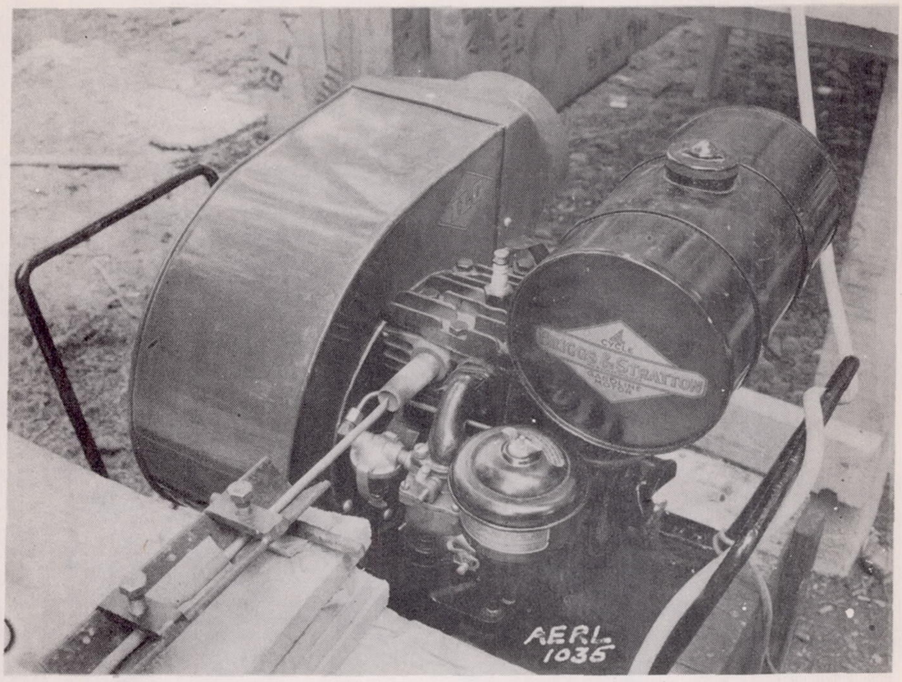



Figure 1. - Sampling tube at open end of exhaust stack of Briggs & Stratton engine.

#42



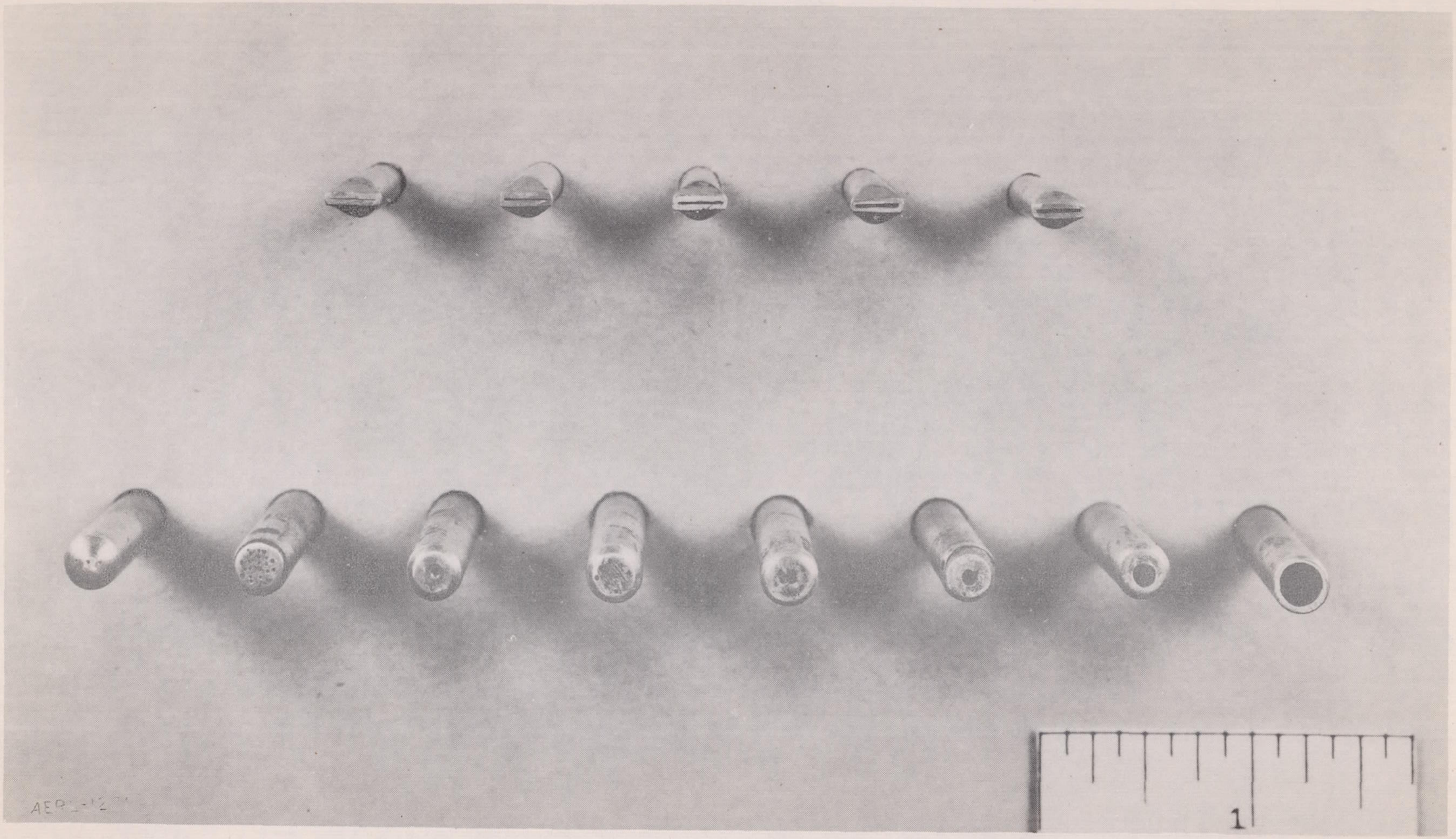



Figure 2. - Round orifices 0.0135 inch to 0.1875 inch in diameter and slot orifices 0.002 inch to 0.016 inch in width.

#42



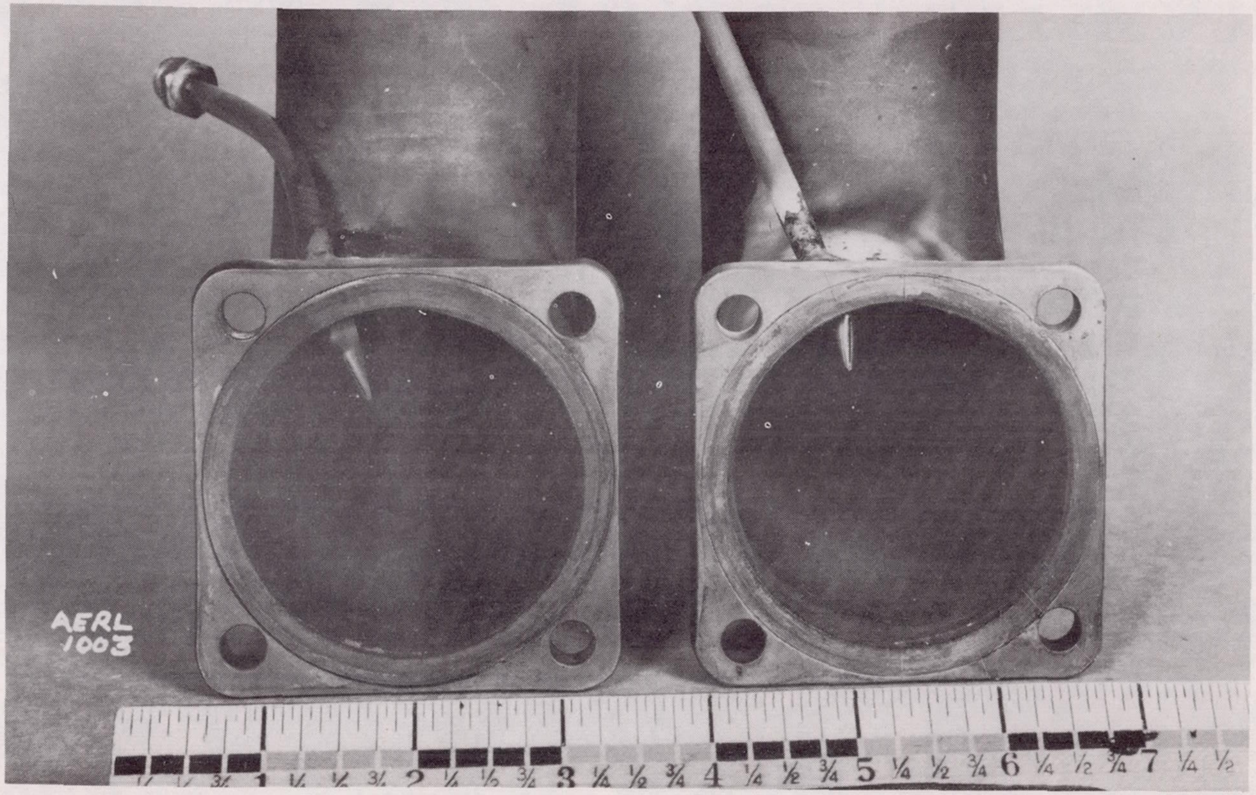



Figure 3. - First position and corrected position of 0.010-inch orifice in front cylinder exhaust stack to obtain impact pressure of exhaust gases.

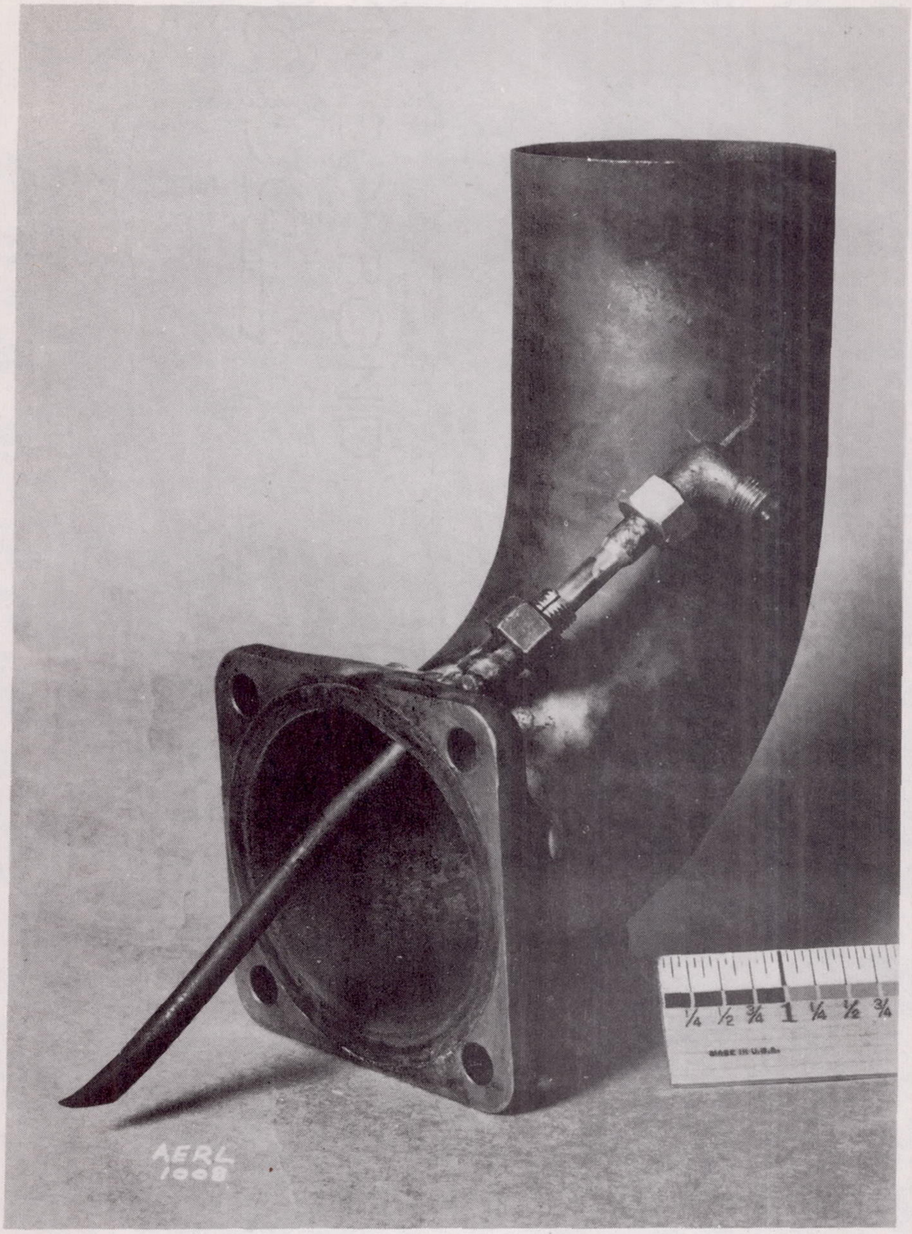



Figure 4. - Adjustable tube with 0.010-inch orifice to study impact pressure in exhaust stack.

#42



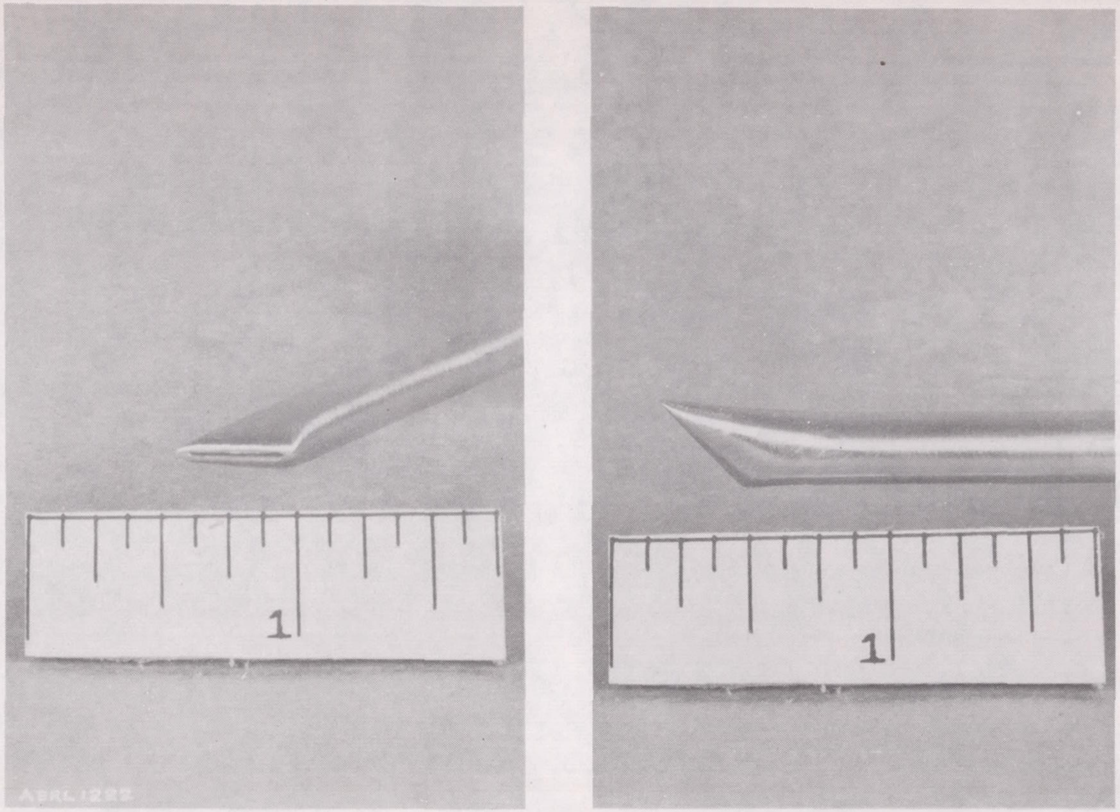



Figure 5. - Front and side view of 1/4-inch stainless-steel sampling tube with 0.010-inch slot orifice.

#42



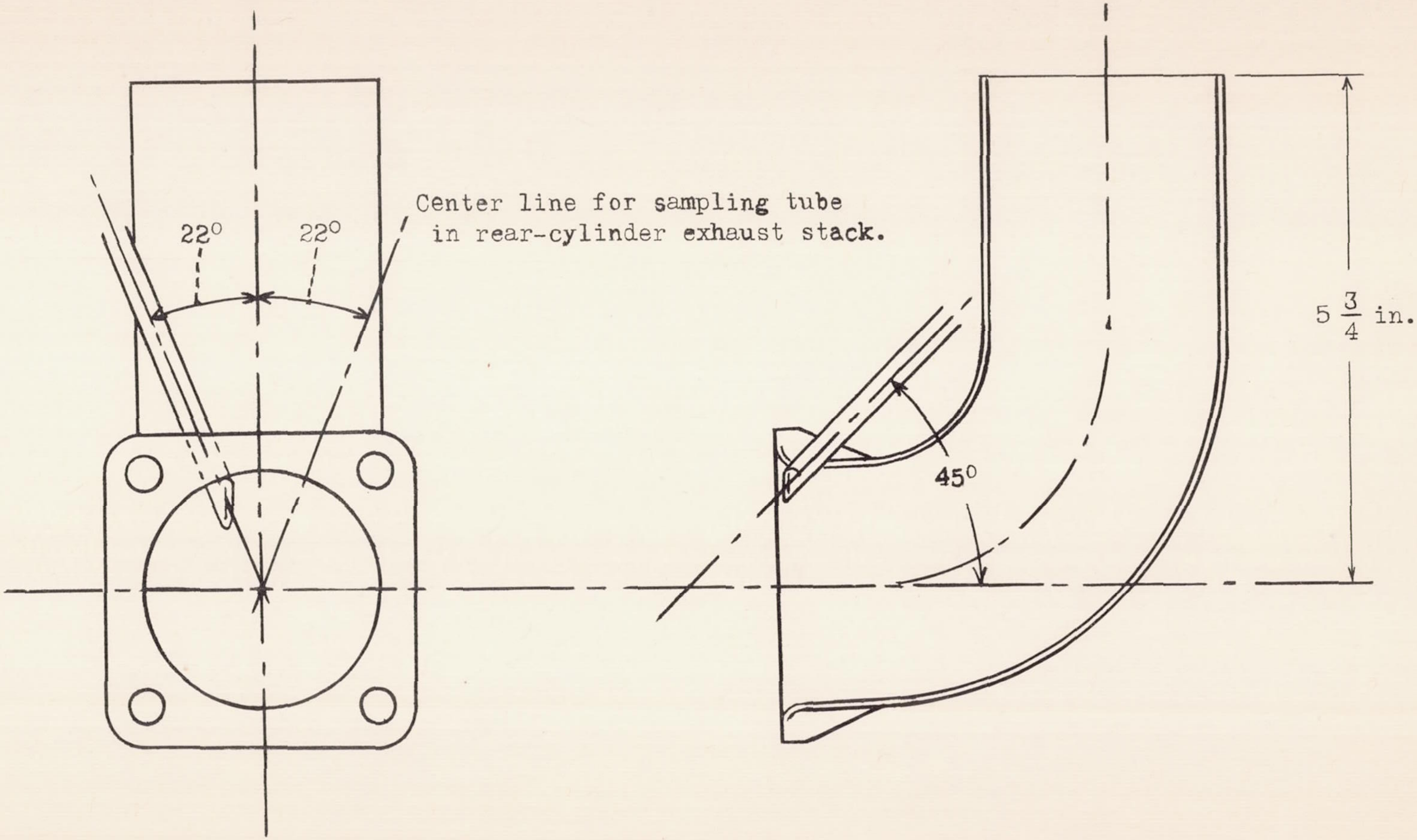
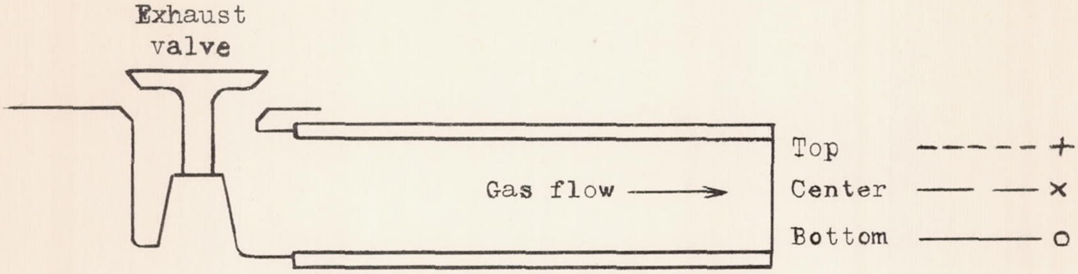



Figure 6.- Sampling tube in aircraft-engine front-cylinder exhaust stack.



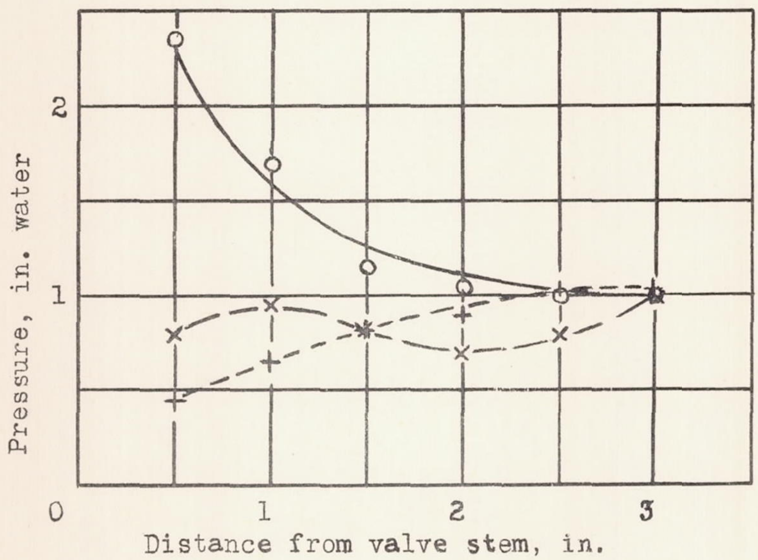




Figure 7.- Pressure distribution in exhaust stack.

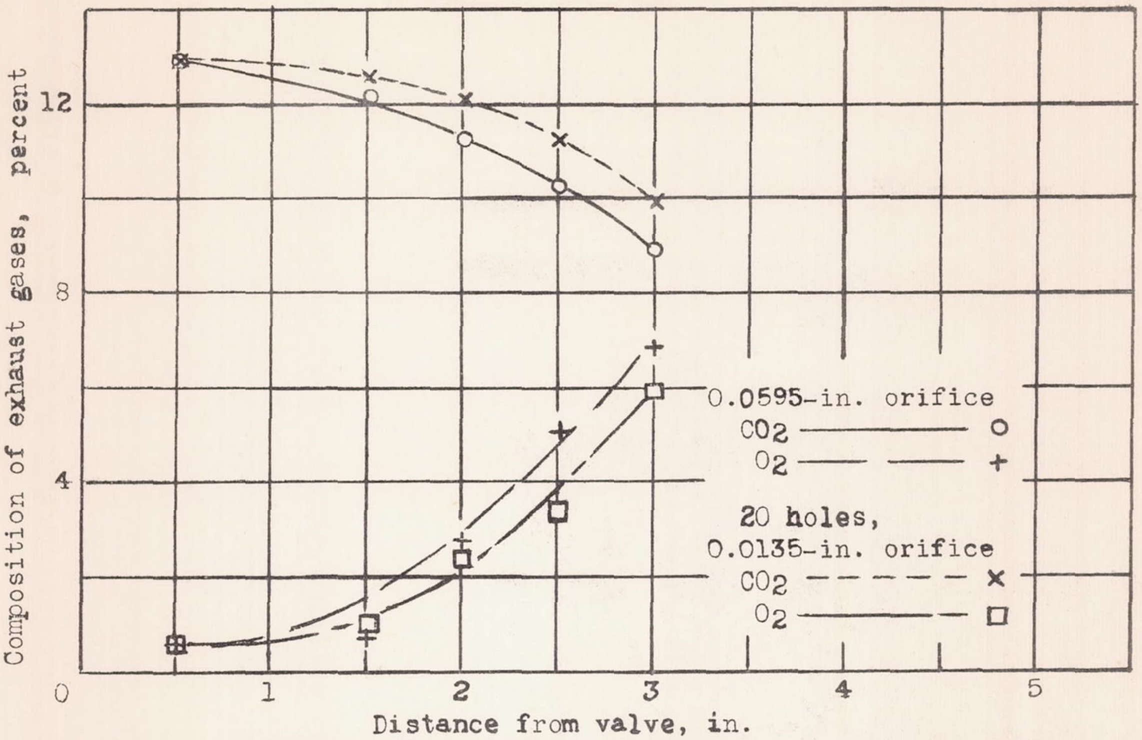



Figure 8.- Effect of orifice size on composition of gas samples, at equal rates of sampling.

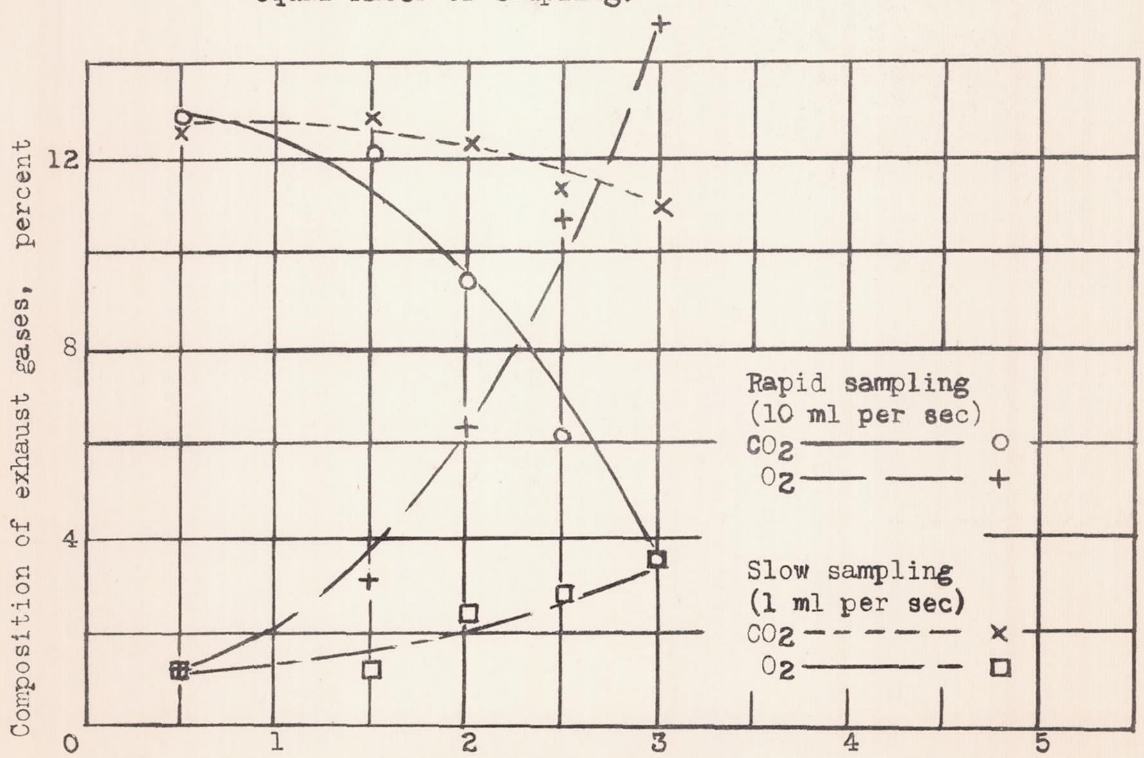



Figure 9.- Effect of rate of sampling on composition of gas samples (orifice-slot width, 0.002 in.).

#42

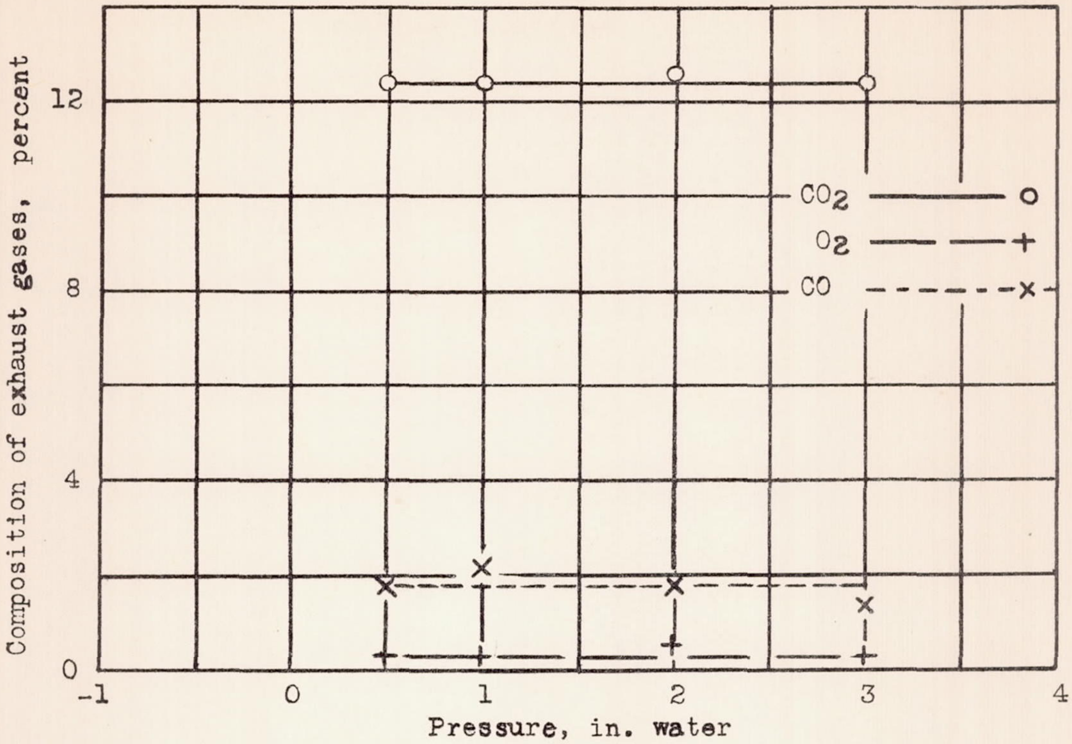



Figure 10.- Effect of sampling pressure on composition of gas sample when dilution is not encountered (20 holes, 0.0135-in. diameter, 1/2 in. from valve).

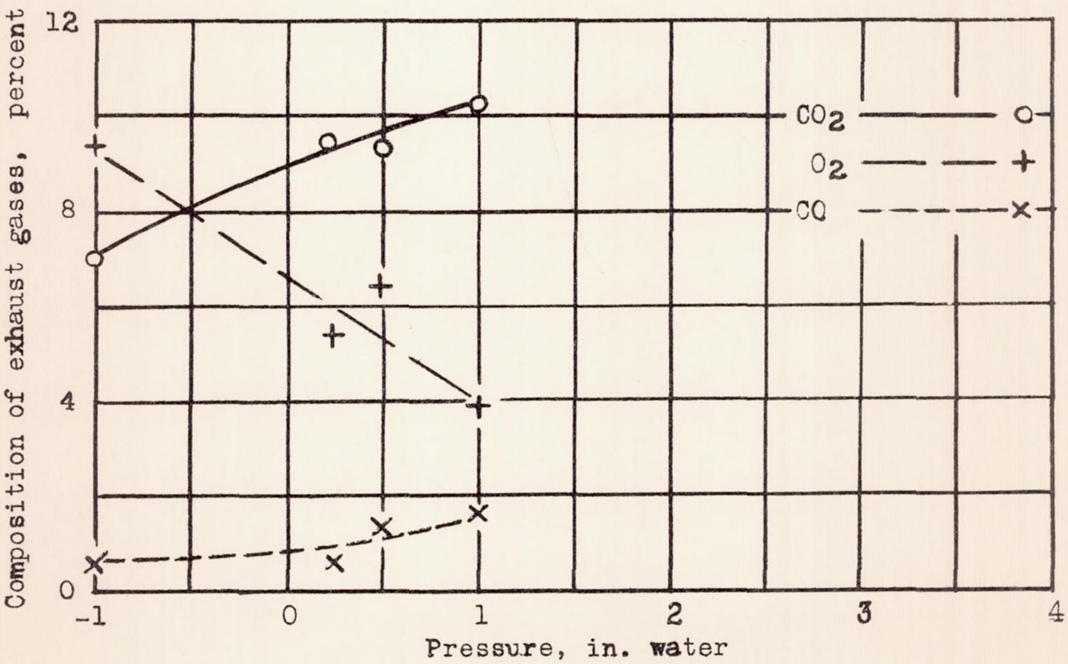



Figure 11.- Effect of sampling pressure on composition of gas sample when dilution is encountered (20 holes, 0.0135-in. diameter at open end of stack).

#42

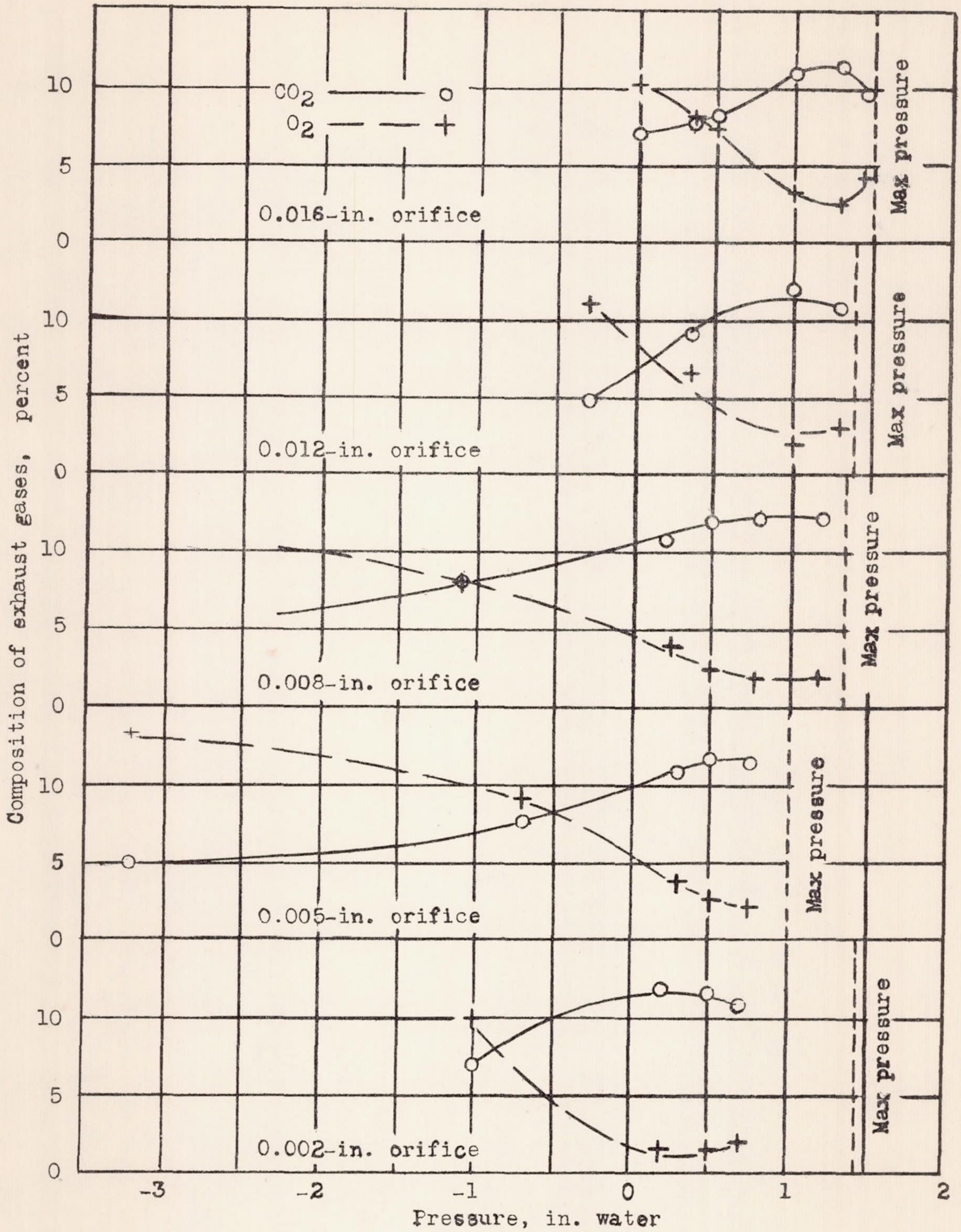
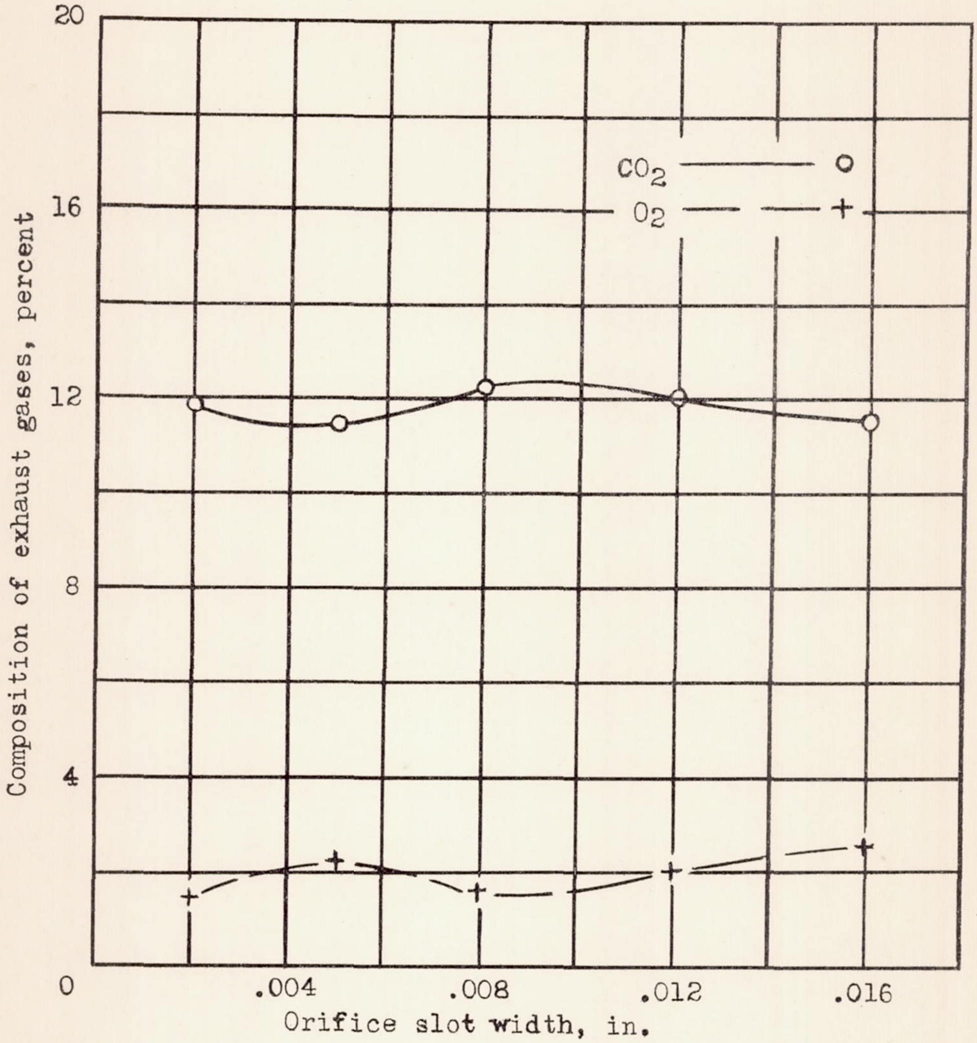



Figure 12.- Effect of sampling pressure on composition of exhaust samples at open end of exhaust stack (slot orifices).

#42




\# 42

Figure 13.- Comparison of best analyses for various slot orifices used at open end of exhaust stack.

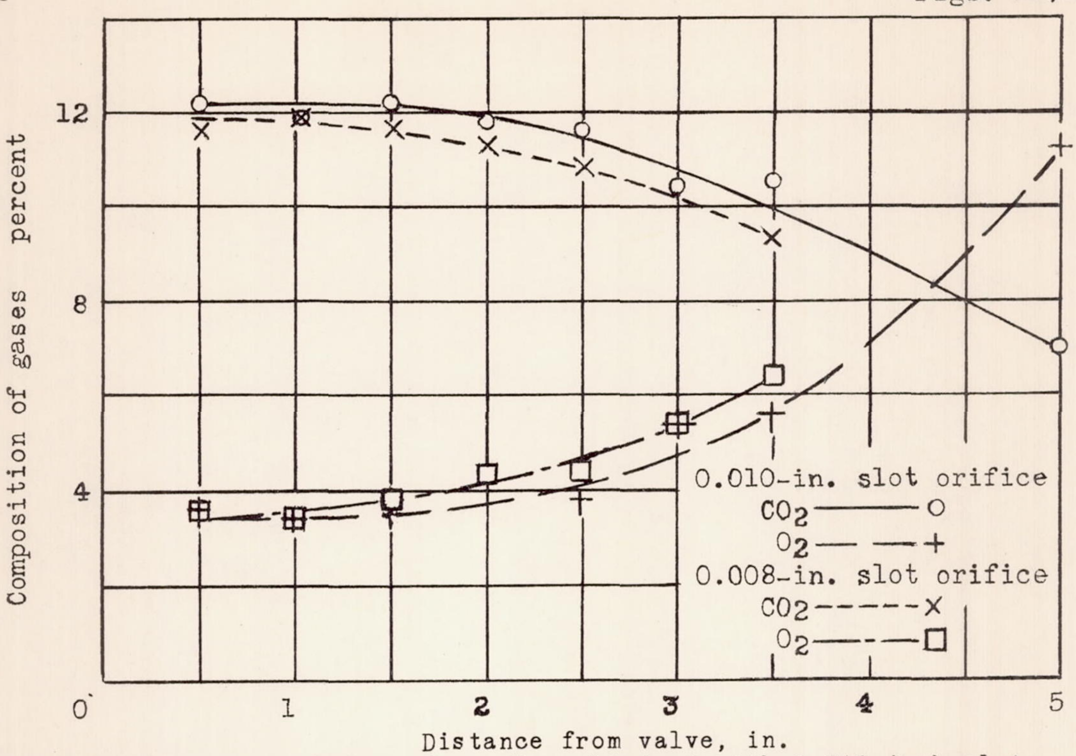



Figure 14. - Composition of samples obtained with 0.010-inch slot orifice and 0.008-inch slot orifice. Pressure, approximately 90 percent of maximum obtainable in sampling tube.

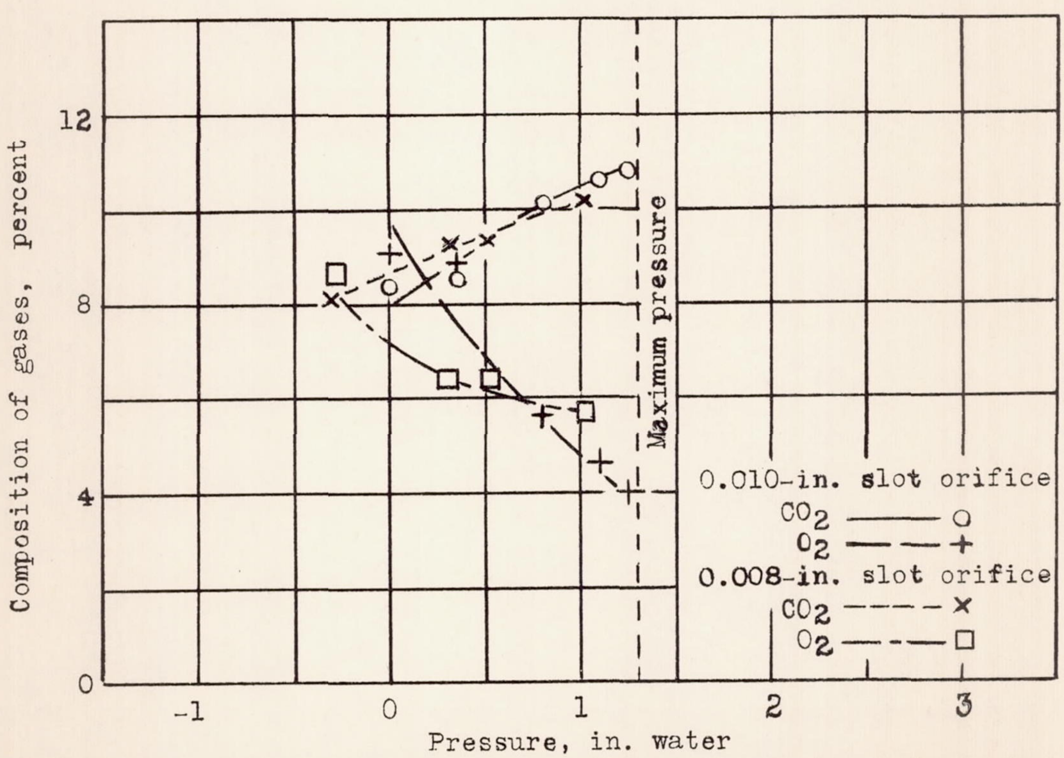



Figure 15.- Effect of sampling pressure on composition of sample obtained with 0.010-inch slot orifice and 0.008-inch slot orifice at open end of exhaust stack.